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(54) Combined equalizer and spread spectrum interference canceller method and implementation for the downlink of CDMA systems

(57) The present invention describes a method and apparatus for implementing a mobile receiver (10) that combats multiple access interference (MAI) in a code division multiple access (CDMA) spread spectrum system. Such capability is required by mobile receivers to support high data rate applications such as the ones provided by HSDPA and 1xTREME. A receiver (10) combining equalization and interference cancellation (IC), according to the invention, avoids the shortcomings of either equalization or IC and provides superior performance relative to prior art methodologies. The approach proposed by this invention for the operation of the mobile receiver is to first perform equalization (12) of the received signal (r) and then use the resulting decisions to perform IC. Combining equalization and IC yields a complexity that is smaller to that obtained by implementing conventional IC with a Rake receiver for the same performance.

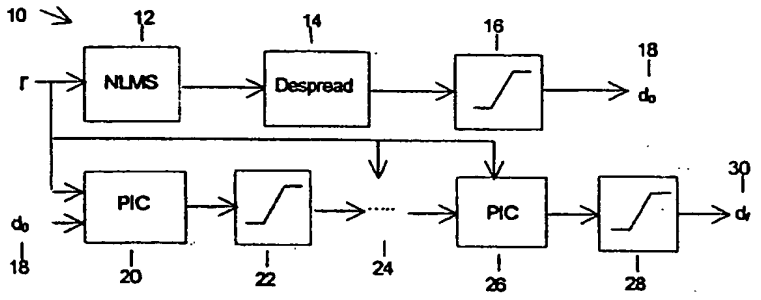

Figure 1

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Description

TECHNICAL FIELD OF THE INVENTION

[0001] This invention relates to the forward link (downlink) of CDMA communications systems in multipath propagation environments where each received signal path experiences interference from other signals and other paths of the same signal. It presents a novel method to suppress interference by combining equalization and interference cancellation. It also describes an implementation for the disclosed combined equalization and interference cancellation method.

BACKGROUND OF THE INVENTION

[0002] Code division multiple access (CDMA) has been extensively used in such applications as cellular and satellite communications. CDMA signals increase the spectrum required for the transmission of a particular data rate by modulating each information symbol with a spread spectrum code having a rate larger than the data rate. The same spreading code is used for each information symbol. Typically, the spreading code comprises of a few tens or a few hundreds elements, called chips. To decrease the correlations among spreading codes assigned to different users and thereby reduce the interference among different users, the data stream after spreading is typically scrambled with a pseudo-noise (PN) code that is generated serially and cyclically and has a larger period than the spreading code. Examples of such CDMA signal spreading are the schemes used by the IS-95/CDMA2000 and 3GPP systems.

[0003] With CDMA, the signals from all users simultaneously occupy the same frequency band. The receiver discriminates the multiple signals by exploiting the properties of the spreading and scrambling codes that are applied to the signal of each user. The receiver attempts to match in time with the codes of the desired signal a replica of those spreading and scrambling codes. Only then the demodulation result is meaningful; otherwise it appears noise-like. Thus, if the arriving signals have different codes or different code offsets, they can be discriminated at the receiver.

[0004] In the forward link of cellular communication systems, i.e. the communication from base stations to mobile terminals, the wireless channel may introduce multipath propagation. Even if the signals transmitted by the base station are spread using orthogonal codes (Walsh codes), the multipath propagation will destroy the orthogonality and produce multiple-access interference (MAI).

[0005] Interference cancellation (IC) attempts to suppress the MAI by estimating and subtracting the interference from the received signal, as disclosed in U.S. Patent 5,553,062 to Schilling. Because the capacity of CDMA systems is typically MAI limited, estimating and canceling the MAI will increase the capacity. Alternatively, IC can reduce the symbol or frame error rate thereby allowing communication with higher data rates.

[0006] Equalization also attempts to suppress the MAI by restoring the orthogonality of the transmitted signals at the receiver. This is accomplished by inverting the effects introduced by the channel due to multipath propagation, as disclosed in "Multiple Access Interference Suppression with Linear Chip Equalizers in WCDMA Downlink Receivers", K. Hooli, et. al, pp. 467-471, Globecom 1999.

[0007] Conventional IC schemes use knowledge of the spreading and scrambling codes used to transmit the signals, the decisions from a Rake receiver, and a channel estimate to reconstruct the components of the received signal and remove the interference, as disclosed in U.S. Patent 5,553,062 to Schilling. The Rake receiver is however highly suboptimal in the presence of interference, particularly for higher order data modulations such as QAM. The data decisions provided by the Rake have poor reliability and when used by IC to reconstruct the interference they can result in significant performance degradation since the estimated received signal components are not very accurate. Subsequent cancellation of the estimated interference can therefore result in worse performance than the one of the Rake receiver since additional interference may be introduced due to erroneous decisions.

[0008] Conventional equalization methods try to either adapt to a known signal, such as the common pilot signal transmitted in the downlink of CDMA systems, or attempt to estimate or adapt to the channel impulse response and then use it to reverse the impact of multipath propagation on the received signal. Examples of well-known equalizers based on adaptation are the NLMS and its variants while equalizers based on channel inversion are the MMSE and its variants, as disclosed in "Multiple Access Interference Suppression with Linear Chip Equalizers in WCDMA Downlink Receivers", K. Hooli, et. al, pp. 467-471, Globecom 1999. Although outperforming the Rake receiver in interference environments, equalization methods perform worse than IC when interference from signals transmitted to other mobile users in the same cell is low to moderate and generally have similar performance to IC in high interference environments.

SUMMARY OF THE INVENTION

[0009] A method and apparatus for implementing a mobile receiver combating multiple access interference (MAI) in

a code division multiple access (CDMA) spread spectrum system. In particular, the method applies to any mobile receiver capable of despreading multiple CDMA codes used to spread signals transmitted by a base station. Such capability is required by mobile receivers to support high data rate applications such as the ones provided by HSDPA and 1xTREME. More particularly, the invention combines interference cancellation (IC) and equalization in order to avoid the previous shortcomings of individual equalization or IC. By replacing the Rake receiver with an equalizer, the proposed receiver avoids having the poor performance of the Rake impacting the IC performance. Moreover, because of the better reliability of the initial decisions provided to IC, the required number of IC stages to achieve certain performance requirements may be drastically reduced, thereby decreasing the total receiver complexity. By using IC after equalization, the proposed receiver enhances the performance of equalizers by also using IC. The complexity of the proposed receiver is similar or smaller to that of a receiver implementing conventional IC using the decisions of a Rake receiver and is only moderately larger than that of a receiver only implementing an equalizer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIG. 1 illustrates an exemplary embodiment of a receiver using equalization and interference cancellation (IC), according a preferred embodiment of the invention.

FIG. 2 illustrates a graph of the performance of one implementation of an HSPDA receiver.

FIG. 3 illustrates a graph of the performance of another implementation of an HSPDA receiver.

FIG. 4 illustrates a graph of the performance of still another implementation of an HSPDA receiver.

FIG. 5 illustrates a graph of the performance of yet another implementation of an HSPDA receiver.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0011] The present invention is best understood in relation to FIGS. 1-5 of the drawings, like numerals being used for like elements of the various drawings. The preferred embodiments of the invention and corresponding performance benefits relative to the established approach will now be described.

[0012] The following description applies to the mobile receiver (or user equipment UE) of a code division multiple access (CDMA) communication system.

[0013] A high speed data downlink access (HSPDA) format, such as described in TSG-RAM Working Group 1, "Physical Layer Aspects of UTRA High Speed Downlink Packet Access", ETSI 3GPP 3G TR25.848 V0.6 (2000-05), March 2001 (available on www.3gpp.org) will be considered to describe the invention. However, the invention also applies to the 3GPP Release 1999, 3GPP2, 1xTREME, and to any other CDMA system employing orthogonal spreading in the downlink.

[0014] In HSDPA, the UE is assigned a number of orthogonal codes with spreading factor (SF) of 16. The remaining orthogonal codes of SF=16 may form the root or by a branch of the code tree for codes used by other UEs in the same cell and are also orthogonal to the codes used by the HSDPA UE. The existence of multipath propagation destroys the orthogonality in the downlink and the performance of a Rake-based UE receiver is MAI-limited experiencing an error floor. This error floor is particularly severe for amplitude modulations, such as 16-QAM and 64-QAM, that are associated with high data rate transmissions. It is therefore of utmost importance to alleviate the impact of MAI in order to enable the use of spectrally efficient modulations and support high data rate applications.

[0015] Conventional interference cancellation (IC) suppresses MAI by despreading each signal, making a decision for the value of the corresponding information symbol with a Rake receiver, using the knowledge of the scrambling and spreading codes and a channel estimate to regenerate the corresponding received signal component, and subtracting it from the received signal. In HSDPA, this approach may consider the multicodes corresponding to the UE as well as known interferers, such as the pilot signal, and IC may by performed according to any of many known techniques. By using decisions based on the Rake receiver the performance of IC may degrade significantly because of the poor reliability of the Rake decisions in multipath propagation environments with MAI. This is particularly true for the initial Rake decisions performed before the first IC stage because they are based on a signal experiencing the whole MAI. Subsequent IC stages reduce the amount of MAI in the received signal and the performance of the Rake receiver is drastically improved. To address the poor reliability of the initial Rake decisions, those decisions are weighted by a small value. This in turn implies that only a small portion of the interference is cancelled during the first IC stage.

Subsequently, as the reliability of the decisions is improved, larger weights and larger portion of the interference are used for cancellation in the next IC stages. An implication of this approach is that several IC stages are needed before 100% of the interference is considered for cancellation. Using an equalizer to provide the initial decisions, those decisions are more reliable than the ones from the Rake receiver and as a result large portions of the interference may be cancelled immediately, thereby substantially reducing the total number of IC stages required to achieve certain performance specifications. Thus, by replacing the Rake receiver and several IC stages with an equalizer, the resulting complexity can be reduced, especially if a linear and simple equalizer such the NLMS is used, while achieving similar performance.

[0016] Equalization has so far been considered as an alternative approach to IC and the application of equalizers in the CDMA downlink has been extensively studied in the prior art. However, equalization approaches cannot provide better performance than conventional IC in fast fading channels or for low to moderate MAI from other UEs in the same cell and their performance is comparable to that of IC in slow fading high interference environments.

[0017] The proposed receiver implementation combines equalization and IC to achieve bit error rate (BER) and frame error rate (FER) suitable for HSDPA or other high data rate systems. An equalizer, such as the NLMS or the linear MMSE, replaces the Rake receiver. Equalization is performed at the chip rate, if the delays of the received paths are known and their separation is larger than 1 chip, or at subchip rate is the requirements for chip-rate operation do not hold. The equalizer length (for chip rate equalization) needs only be about 2 times the delay spread of the strongest paths and paths that are weaker by more than 10 dB relative to the strongest path need not be within the span of the equalizer. The IC process remains the same as with the one using a conventional Rake receiver.

[0018] The NLMS is considered as an example for an equalizer and is described below.

Parameters: μ is the adaptation coefficient ($0< \mu <2$);

L - NLMS length

Data at time n: $\bar{r}(n)$ - received signal after receiver's filter;

$w(n)$ - equalizer tap coefficients; $x(n)=w^H(n)\bar{r}(n)$ - NLMS output;

$d(n)$ - desired response, i.e., pilot chip.

Initialisation:

$$w(0)=0$$

Computation:

output signal:

$$x(n)=w^H(n)\bar{r}(n)$$

error signal:

$$e(n)=d(n)-x(n)$$

weight update:

$$w(n+1)=w(n)+\frac{\mu}{\{Wr(n)\}^2}\bar{r}(n)e^*(n)$$

[0019] A comparison for the NLMS complexity relative to that of the Rake is given below in terms of the required operations/sec. L_e denotes the length of the equalizer, and R_c is the chip rate. The adaptation step size μ is assumed to be power of two, i.e., $\mu = 2^{\gamma}$. Thus the multiplications with the adaptation step size can be replaced by shifting the numbers. With this assumption, the multiplications with μ are excluded from Table 1.

	# of additions	# of multiplications
$x(n)=w^H(n)r(n)$	$(4L_e-2)R_c$	$4L_eR_c$
Update w	$(4L_e+2)R_c$	$4L_eR_c$
Correlation/code	$4R_c$	-
Total	$8L_eR_c+4R_c$	$8L_eR_c$

Table 1. Number of operations per second for CPICH-trained NLMS.

[0020] For comparison, the Rake complexity is given in Table 2. The number of fingers is N_f and the symbol rate is R_s. Correlation is performed by sign operations and accumulation.

	# of additions	# of multiplications
Correlation/code	$4N_fR_c$	-
MRC/code	$2(2N_f-1)R_s$	$4N_fR_s$
Total	$4N_fR_c + 2(2N_f-1)R_s$	$4N_fR_s$

Table 2. Number of operations per second for Rake receiver.

[0021] Consider a chip-spaced NLMS equalizer (path arrival time is known and paths are distinct - no need for a fractionally spaced equalizer) and the HSDPA setup (R_c=3.84e6, R_s=2.4e5). Also assume a multipath delay spread of about 4 chips and 4 fingers (ITU Vehicular A channel with the two weakest paths neglected (they are at -15dB and -20 dB relative to the first path)). The equalizer length is about 11 chips. An approximate comparison of the complexity between Rake and NLMS is given in Table 3. Both the NLMS and Rake have smaller complexity for Pedestrian channels.

	# of additions	# of multiplications
Rake (10/5 codes)	0.72e9/0.43e9	0.04e9/0.025e9
NLMS (10/5 codes)	0.50e9/0.42e9	0.34e9/0.34e9

Table 3. Number of operations per second for Rake and NLMS.

[0022] Table 3 shows that the NLMS and the Rake have similar complexity in terms of the required additions but the NLMS requires 1 order of magnitude more multiplications. This is because the equalizer coefficients are real numbers and, unlike despreading, actual multiplications are needed. Clearly, from an implementation standpoint, the NLMS is feasible and has comparable complexity to the Rake receiver.

[0023] Parallel IC is considered in the exemplary embodiment. A description of PIC can be found in U.S. Patent 5,553,062 to Schilling. A brief mathematical description of PIC is now given. Let $\tilde{c}_{l,k}^{(p)}(t)$ be the complex channel estimate and $\tilde{d}_k^{(p)}(t)$ be the estimated data for the l^{th} path ($1 \le l \le L$) of the k-th HSDPA code ($1 \le k \le 10$) at the p^{th} stage

(typically, $1 \le p \le 4$). The multipath interference replica $\hat{I}_l^{(p)}(t)$ of the p^{th} stage is expressed as

$$\hat{I}_l^{(p)}(t-\hat{\tau}_l) = \sum_{l=1}^{L} \tilde{c}_l^{(p)}(t)\left(\sum_{k=1}^{K} \tilde{d}_k^{(p)}(t-\hat{\tau}_l) \cdot s_k(t-\hat{\tau}_l) + s_{cpich}(t-\hat{\tau}_l) \right)$$

where $s_k(t)$ and $s_{cpich}(t)$ represent the spreading for the k^{th} multicode and the pilot, respectively. Also, $\hat{\tau}_l$ is the estimated delay time of the l^{th} path. By using $\hat{I}_l^{(p)}(t)$ and received signal $r(t)$, the input signal, $r_l^{(p+1)}(t)$ for the l^{th} path at the $(p+1)^{th}$ stage is represented as

$$r_l^{(p+1)}(t) = r(t) - \alpha \sum_{\substack{j=1 \\ j \neq l}}^{L} \hat{I}_j^{(p)}(t-\hat{\tau}_j)$$

where α is the real-valued weighting coefficient ($0 < \alpha \le 1$) and accounts for the bias in the interference estimate. Typically, α=0.6-0.8 for p=1 and α=1.0 for p>1.

[0024] According to the invention, the Rake receiver of the prior art may be replaced by an equalizer at every IC stage. The main benefits however result from having an equalizer to provide the decisions before the first IC stage. This is because the MAI the Rake receiver experiences is largely removed even after one IC stage if the MAI is accurately estimated and reconstructed. This is the case if an equalizer replaces the initial Rake receiver. The IC process can also be enhanced to suppress interference caused by signals transmitted to other UEs served by the same base station. In the proposed receiver implementation, the equalizer may or may not replace the Rake receiver after the first IC stage. The equalizer always replaces the Rake receiver before the first IC stage. Moreover, even though a linear equalizer is typically a 2-3 times more complex than the Rake receiver, it is less complex than each IC stage. Thus, if the combination of an equalizer and IC results to a reduction in the number of stages required to achieve the same performance requirements relative to the conventional IC structure (initial decisions to IC provided by a Rake receiver), the overall complexity of the receiver is reduced.

[0025] Figure 1 illustrates a preferred embodiment of a high-speed data downlink access receiver 10. Receiver 10 may be implemented in a base band processor of a receiver of a code division multiple access (CDMA) communication system. Equalizer 12, such as an NLMS or other linear equalizer known in the art, is coupled to receive a receive signal r in said base band processor subsequent to analog-to-digital (A/D) conversion. Accordingly, receive signal r is a digital signal. Despreader 14, implementing matched filtering with a specific spreading code, couples equalizer 12 to a decision block 16, which may perform hard, soft, soft-clipped, and/or other decision known in the art. The decision stream 18 from decision block 16 is coupled together with the received signal r to parallel interface canceller (PIC) 20. PIC 20 implements interference cancellation, despreading and the Rake receiver. The output of the Rake receiver inside PIC 20 is fed again to a decision device 22. The new decisions are used for the next IC stages and decision devices 24, if any. The process is finally terminated at the last IC stage 26 and the last decision device 28 provides the final decisions used for further processing (e.g. deinterleaving, decoding, etc). Equalizer 12 replaces the Rake of the prior art in providing the initial decisions to a parallel IC method. The IC is then implemented as usual or the equalizer may also replace the Rake receiver in the IC block.

[0026] Figure 2 is a graph that illustrates the performance in terms of uncoded bit error rate (BER) for an HSDPA receiver, according to one embodiment of the invention. In the case of Figure 2, the bit error rate (BER) for 10 SF=16 HSDPA Codes for an ITU Vehicular A Channel.

[0027] Figure 3 is a graph that illustrates the performance in terms of frame error rate (FER) for an HSDPA receiver, according to another embodiment of the invention. In the case of Figure 3, the frame error rate (FER) for 10 SF=16 HSDPA Codes for an ITU Vehicular A Channel. Rate ¾ Turbo Code.

[0028] Figure 4 is a graph that illustrates the performance in terms of uncoded bit error rate (BER) for an HSDPA receiver, according to yet another embodiment of the invention. In the case of Figure 2, the bit error rate (BER) for 6 SF=16 HSDPA Codes for an ITU Vehicular A Channel.

[0029] Figure 5 is a graph that illustrates the performance in terms of frame error rate (FER) for an HSDPA receiver, according to still another embodiment of the invention. In the case of Figure 5, the frame error rate (FER) for 10 SF=16 HSDPA Codes for an ITU Vehicular A Channel. Rate ¾ Turbo Code.

[0030] Figures 2-5 present the performance in terms of uncoded bit error rate (BER) and frame error rate (FER) for several alternative implementations of an HSDPA receiver. These implementations include the Rake receiver, the con-

ventional parallel IC with soft decisions as an exemplary IC method, the NLMS as an exemplary equalization method, and the proposed implementation combining equalization and IC and equalization. Two cases of 10 and 6 HSDPA codes transmitted to the UE are presented. Figures 1 and 3 present the BER for the aforementioned cases, while Figures 2 and 4 present the FER for a turbo code with rate ¾. Both BER and FER are presented as a function of the ratio (Ior/Ioc) of the total received power transmitted by the UE's base station at the UE (Ior) to the power from other cells and thermal noise (Ioc). The ITU Vehicular A model was considered. From the figures it becomes evident that the proposed implementation for the HSDPA receiver considerably outperforms the exemplary IC and equalization methods and can provide FER values below 0.1 for an extensive range of Ior/Ioc values. This conclusion also holds for a variety of other channel realizations and IC and equalization methods.

[0031] In addition to superior performance relative to other receiver implementations, the combination of equalization and IC proposed in this invention also has smaller complexity for the same performance requirements. An equalizer typically requires only a few times more operations that the Rake receiver while each IC stage is more complex than the equalizer. Thus, even if one IC stage is eliminated, the resulting complexity of the disclosed receiver structure is smaller than the conventional one using the Rake receiver to provide the initial decisions to the IC. It is usually possible to eliminate more than one IC stages and still achieve the required performance, thereby obtaining significant complexity savings.

[0032] Although the Detailed Description of Preferred Embodiments has been directed to certain exemplary embodiments, various modifications of these embodiments, as well as alternative embodiments, will be suggested to those skilled in the art. The invention encompasses any modifications or alternative embodiments that fall within the scope of the claims.

Claims

1. A method of demodulating an information signal of a communication system in an electronic device, comprising the steps of:

   equalizing a received signal;
   despreading the received signal after said equalizing;
   making a decision for information symbols after said despreading;
   estimating a channel medium; and
   using the decision for the information symbols and the estimate of the channel medium to perform interference cancellation on the received signal.

2. The method of Claim 1, wherein said communication system is a code division multiple access (CDMA) communication system.

3. The method of Claim 1, wherein said communication system is a code division multiple access (CDMA) communication system in a multipath propagation environment where each received signal path experiences interference from other signals and other paths of the same signal.

4. The method of Claim 1, wherein said despreading includes use of spreading codes.

5. The method of Claim 1, wherein said despreading includes use of scrambling and spreading codes.

6. A method of despreading multiple codes in an electronic device, comprising the steps of:

   equalizing a received signal;
   despreading the received signal after said equalizing;
   deciding the value of information symbols associated with said received signal after said despreading;
   estimating a channel medium; and
   using the decided value of said information symbols and the estimate of the channel medium to perform interference cancellation on the received signal.

7. The method of Claim 6, wherein said electronic device is a code division multiple access (CDMA) communication receiver.

8. A receiver, comprising:

an equalizer for equalizing a received signal;
a despreader for despreading the received signal after said equalizing;
an interface cancellation circuit having an input for receiving said received signal;
decision circuitry, for coupling said interface cancellation circuit to said despreader; and
second decision circuitry, for coupling decode processing circuitry to said interface cancellation circuit.

9. The receiver of Claim 8, wherein said despreader implements spreading codes.

10. The receiver of Claim 8, wherein said despreader implements scrambling and spreading codes.

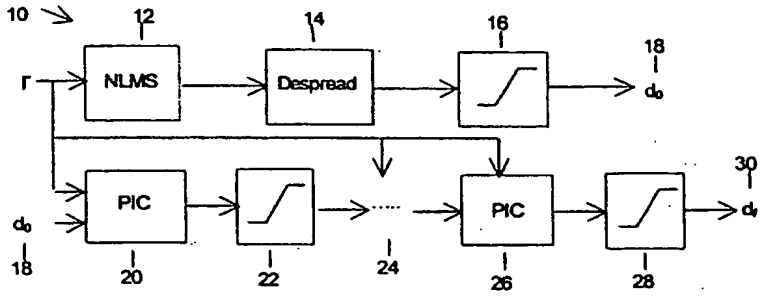

Figure 1

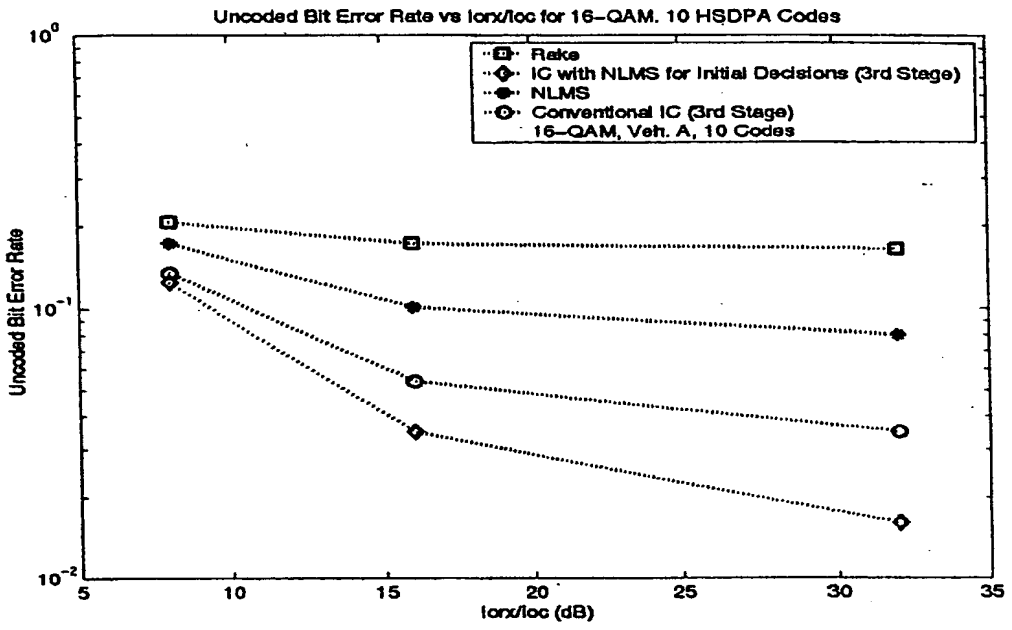
Uncoded Bit Error Rate vs Ior/Ioc for 16-QAM, 10 HSDPA Codes
Rake
IC with NLMS for Initial Decisions (3rd Stage)
NLMS
Conventional IC (3rd Stage)
16-QAM, Veh. A, 10 Codes
Uncoded Bit Error Rate
Ior/Ioc (dB)
10^0
10^-1
10^-2
5
10
15
20
25
30
35

Figure 2

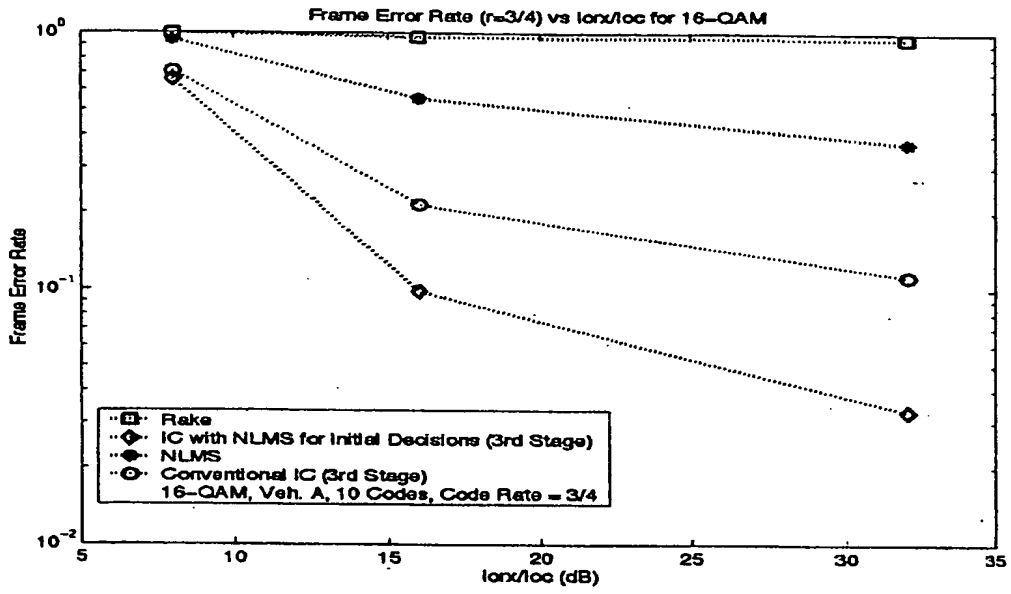
Frame Error Rate (r=3/4) vs Ior/Ioc for 16–QAM
Frame Error Rate
10^0
10^{-1}
10^{-2}
5
10
15
20
25
30
35
Ior/Ioc (dB)
Rake
IC with NLMS for Initial Decisions (3rd Stage)
NLMS
Conventional IC (3rd Stage)
16–QAM, Veh. A, 10 Codes, Code Rate = 3/4

Figure 3

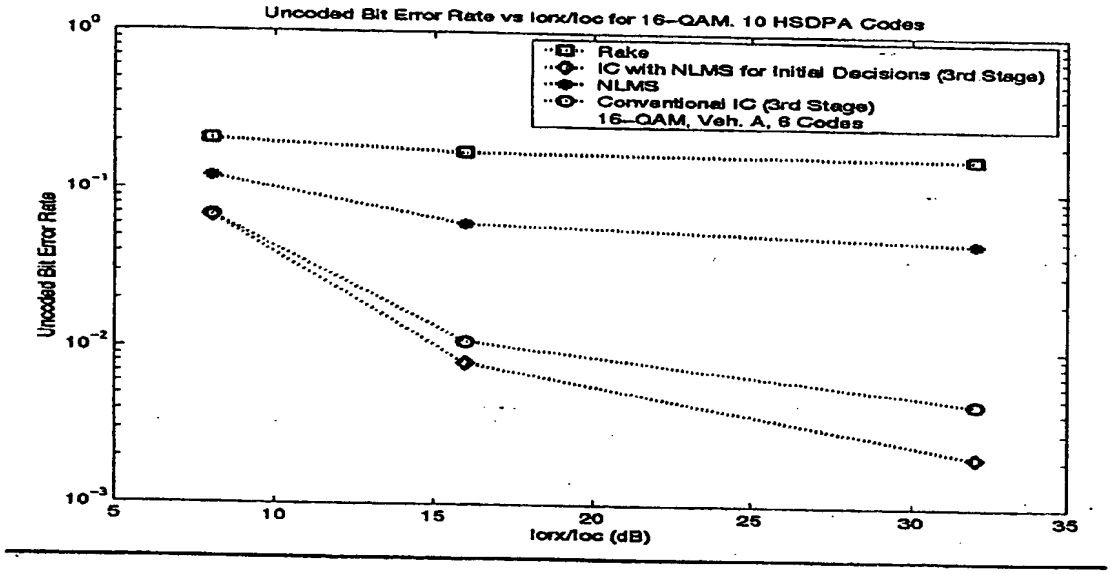
Uncoded Bit Error Rate vs Ior/Ioc for 16–QAM. 10 HSDPA Codes
Rake
IC with NLMS for Initial Decisions (3rd Stage)
NLMS
Conventional IC (3rd Stage)
16–QAM, Veh. A, 6 Codes
Uncoded Bit Error Rate
Ior/Ioc (dB)
10^0
10^-1
10^-2
10^-3
5
10
15
20
25
30
35

Figure 4

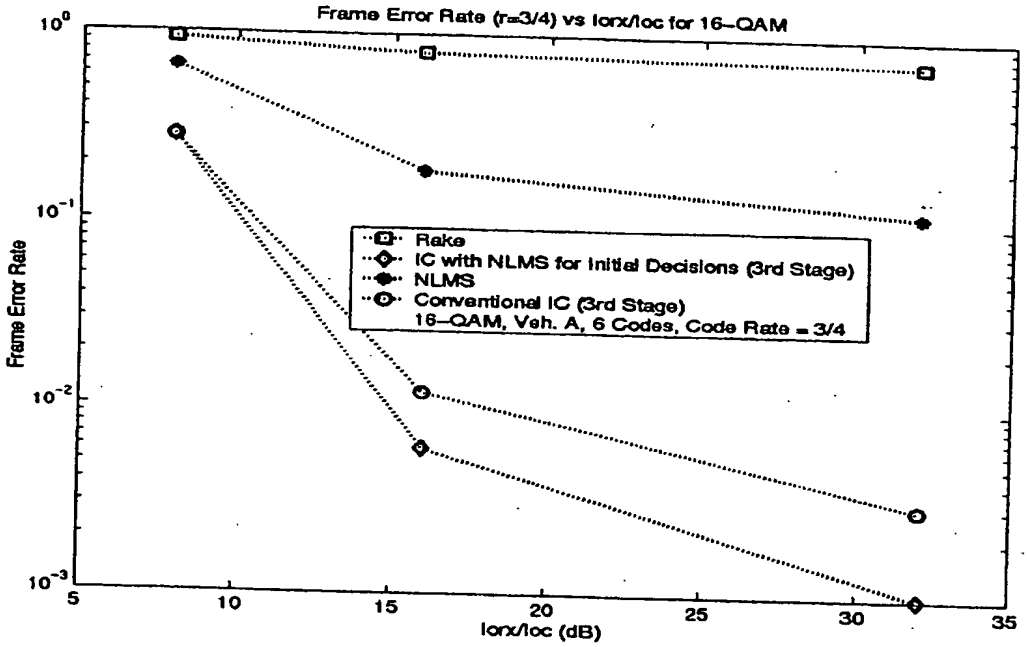
Frame Error Rate (r=3/4) vs Ior/Ioc for 16–QAM
Frame Error Rate
Ior/Ioc (dB)
Rake
IC with NLMS for Initial Decisions (3rd Stage)
NLMS
Conventional IC (3rd Stage)
16–QAM, Veh. A, 6 Codes, Code Rate = 3/4

Figure 5

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(54) Combined equalizer and spread spectrum interference canceller method and implementation for the downlink of CDMA systems

(57) The present invention describes a method and apparatus for implementing a mobile receiver (10) that combats multiple access interference (MAI) in a code division multiple access (CDMA) spread spectrum system. Such capability is required by mobile receivers to support high data rate applications such as the ones provided by HSDPA and 1xTREME. A receiver (10) combining equalization and interference cancellation (IC), according to the invention, avoids the shortcomings of either equalization or IC and provides superior performance relative to prior art methodologies. The approach proposed by this invention for the operation of the mobile receiver is to first perform equalization (12) of the received signal (r) and then use the resulting decisions to perform IC. Combining equalization and IC yields a complexity that is smaller to that obtained by implementing conventional IC with a Rake receiver for the same performance.

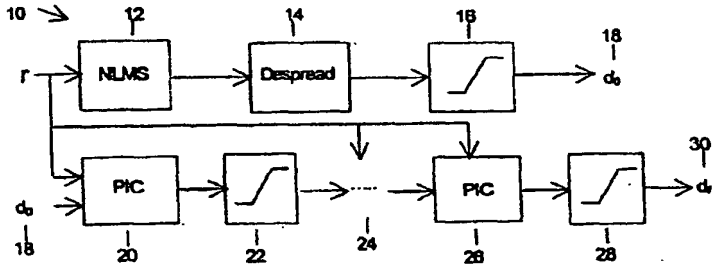

Figure 1

EP 1 289 162 A3

European Patent Office

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Application Number
EP 02 10 2232

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	29 April 2003	Bauer, F

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Place of search	Date of completion of the search	Examiner
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